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Contents

Page

The Relative Sweetness of Various Sweet Compounds and of Their Mixtures—*A. T. Cameron* - - - - - - - 139

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THE RELATIVE SWEETNESS OF VARIOUS SWEET COMPOUNDS AND OF THEIR MIXTURES[1]

BY A. T. CAMERON[2]

Abstract

Responses to specific sweet stimuli are specific for any one individual, but for that individual only. Comparisons as to degree of sweetness of different stimuli may vary from individual to individual. Rigid data are probably unattainable; it is only possible to determine the average opinions of a group of individuals.

The following solutions were found to be equally sweet by the group of individuals employed:

(i) 5.0% sucrose and 8.3% glucose; 10.0% sucrose and 14.4% glucose (which modified the figure previously found, after proper weighting, to 14.6%).

(ii) 5.0% galactose and 2.5% sucrose; 10.0% galactose and 6.0% sucrose; 15.0% galactose and 10.0% sucrose.

(iii) 5.0% mannitol and 2.47% sucrose; 10.0% mannitol and 5.54% sucrose; 15.0% mannitol and 9.8% sucrose.

(iv) 2.0% sucrose and 0.0049% 'soluble saccharine' (approximate only).

(v) 0.0125% dulcine and 3.35% sucrose; 0.025% dulcine and 4.1% sucrose; 0.050% dulcine and 4.6% sucrose (all only approximate).

(vi) 5.0% glycine and 3.25% sucrose; 10.0% glycine and 5.5% sucrose.

(vii) 3.0% *dl*-alanine and 3.0% sucrose.

While it has been shown earlier that the sweetnesses of sucrose and glucose, sucrose and lactose, glucose and lactose, sucrose and glycerol, and glucose and glycerol are additive when calculated in terms of glucose (but not in terms of sucrose), and it is now shown that this is true also for mixtures of galactose and glucose, and (probably) of dulcine and sucrose, this relationship does not hold for mixtures of glycine and sucrose, alanine and sucrose, and alanine and glycine. In such mixtures the total sweetness is *less* than that calculated in terms of glucose and usually less than when calculated in terms of sucrose.

The relative sweetnesses of the group of compounds glucose, galactose, lactose, glycerol, and mannitol, compared with any one of them, do not change with concentration, within the limits of the experimental method used. On the other hand, the relative sweetnesses of these, and of fructose and dulcine, when compared with sucrose, change with concentration, the relationship being a log-log one. There is a similar log-log relationship when comparisons are made with fructose.

A method is described for determining the value of iso-sweet iso-caloric mixtures of glucose and sucrose.

A type curve can be constructed relating sweetness to concentration for glucose and the other compounds of its group. The relationship is log-log. A different log-log relationship between sweetness and concentration holds for sucrose.

[1] *Manuscript received May 23, 1945.*

Contribution from the Department of Biochemistry, Faculty of Medicine, University of Manitoba, Winnipeg, Man.

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Introduction

In previous papers (4, 5) it has been shown that: (i) the majority of people lack a delicate taste sensation for sweetness; (ii) smoking is a factor, but not the sole factor conditioning the delicacy of perception; (iii) alpha-dextroglucose is sweeter than beta-dextroglucose; (iv) the relative sweetnesses of the sugars glucose and lactose and of the alcohol glycerol, as compared with sucrose, vary with concentration; (v) the relative sweetness of glucose or lactose or glycerol, compared with either of the other two, does not change with concentration, within the limits of the experimental method used; (vi) with untrained tasters, the error of measurement is affected more by using too few tasters than by the extent of differences in successive increments of concentration of solutions tasted, and apparently use of 15 to 20 tasters permits reasonably accurate conclusions.

The following have been found to be equally sweet (using equilibrium mixtures of alpha- and beta-glucose and of lactose):

(i) 2.0% sucrose and 3.8% glucose; 10.0% sucrose and 14.7% glucose; 20.0% sucrose and 25.0% glucose.

(ii) 2.0% sucrose and 6.5% lactose; 5.0% sucrose and 14.9% lactose; 8.0% sucrose and 21.7% lactose.

(iii) 2.25% sucrose and 4.0% glycerol; 5.5% sucrose and 8.0% glycerol; 8.9% sucrose and 12.0% glycerol.

It has been demonstrated, for the compounds examined, that the sweetness of a mixture of them of known composition can be expressed in terms of that of a specific concentration of sucrose or of glucose by the following method. The sweetness of each compound is expressed in terms of that one of them for which the rate of change of the ratio of sweetness to concentration is least altered with change of concentration. The arithmetical sum of the values so calculated, referred to the appropriate curve of relative sweetness, gives the corresponding value for a concentration of glucose or of sucrose of sweetness equal to that of the mixture.

This paper records the results of further similar experiments. The following sweetness relationships have been determined: (i) sucrose–glucose (further measurements); (ii) sucrose–galactose; (iii) sucrose–mannitol; (iv) sucrose–dulcine; (v) sucrose–glycine; (vi) sucrose–alanine. In addition the values of certain mixtures have been determined. Comparisons of sucrose and 'soluble saccharine' (the sodium salt of saccharine) did not give satisfactory results.

Paul (16) has given relative figures for the sweetness of saccharine and of dulcine, in terms of sucrose; converting these into relative concentrations of equal sweetness, the results shown in Table I are obtained.

According to earlier observations saccharine is 500 times sweeter than sucrose, sodium saccharine only 400 times (cf., e.g., 18).

Biester *et al.* (2) measured the sweetness of galactose, using a method based on threshold concentrations, which is valueless when sweetness changes with concentration and is open to criticism on other grounds (cf. 4, 5, 6). Their

TABLE I

CONCENTRATIONS OF SUCROSE, SACCHARINE, AND DULCINE OF EQUAL SWEETNESS (AFTER PAUL)

Sucrose, %	Saccharine, %	Dulcine, %	Sucrose, %	Saccharine, %	Dulcine, %
2.0	0.0030	0.0055	7.0	0.028	0.085
3.0	0.0055	0.012	8.0	0.037	0.105
4.0	0.010	0.029	9.0	0.045	0.125
5.0	0.015	0.048	10.0	0.0535	0.143
6.0	0.019	0.067			

results indicated that glucose is more than twice as sweet as galactose; it will be seen that the results now recorded are in complete disagreement with this.

Paul (16) stated that mannitol, as compared (apparently) with 3% sucrose, has a sweetness of 0.45, from which it can be calculated that 3% sucrose and 6.7% mannitol are of equal sweetness.

Heiduschka and his collaborators (12, 13), using Paul's method, compared the sweetness of glycine and sucrose, and of *dl*-alanine and sucrose, and their results, calculated to concentrations of equal sweetness, are shown in Tables II and III. They, like Paul, used Pauli's method of computation (17), which is somewhat complicated. The figures in brackets in Table II have been calculated by the simpler method that I have employed and are obviously in fairly good agreement.

Paul (16) claimed that the degree of sweetness of mixture of saccharine and dulcine is nearly equal to the sum of the sweetness of the single con-

TABLE II

CONCENTRATIONS OF SUCROSE AND GLYCINE OF EQUAL SWEETNESS (HEIDUSCHKA)

Glycine, %	Sucrose, %	Glycine, %	Sucrose, %
2.5	3.0 (3.0)	15.0	9.6 (9.35)
5.0	5.2 (5.5)	20.0	11.0 (10.8)
7.5	6.4 (6.6)	25.0	11.6 (11.75)
10.0	7.9 (7.9)		

TABLE III

CONCENTRATIONS OF SUCROSE AND ALANINE OF EQUAL SWEETNESS (HEIDUSCHKA)

Alanine, %	Sucrose, %	Alanine, %	Sucrose, %
2.5	4.25 (4.4)	7.5	8.0 (8.1)
5.0	6.4 (6.4)	10.0	9.3 (9.4)

stituents (in terms of sucrose). Thus he stated that 0.028% saccharine equalled in sweetness 7% sucrose and that 0.012% dulcine equalled 3% sucrose, while a mixture containing 0.028% saccharine and 0.012% dulcine equalled 10% sucrose.

Heiduschka *et al.* (13) carried out a single experiment to ascertain whether a mixture of alanine and glycine would behave in the same way. They contrasted a mixture of 3.75% glycine plus 3.75% alanine with sucrose solutions and found it equal to 5.8% sucrose, instead of approximately 10%, and concluded that the additive effect did not occur, but drew no further conclusion.

For the experiments now reported 17 students of those used in the second series were available.

Experimental Part

Method

This has already been fully described (5). The experiments are numbered continuously from those recorded in the second paper (5). All the percentage values shown in the stated results indicate weight of the compounds mentioned, in gm. per 100 cc. solution.

Material Employed

Sucrose. Acadia cubes; purity already reported on.

Glucose. "Dextrosol" (dextrose hydrate); purity already reported on.

The following were all purchased from the Eastman Co.:

Galactose. Polarimetric measurement gave specific rotation 78.1° (theory, 80.5°).

Mannitol. M.p. 165° to 167° C. (uncorr.); theory, 166° C.

Dulcine (*p*-phenetylurea). M.p. 169° to 172° C. (uncorr.); theory, 173° to 174° C.

Soluble saccharine (sodium *o*-benzoic sulphimide).

Glycine. M.p. with decomposition 230°–235° C. (uncorr.); theory, 232°–236° C.

dl-Alanine. An attempt was made to determine its purity by formol titration, using thymolphthalein as indicator and the first appearance of a blue colour (pH about 9.3) as end point. This gave the figure 3.06% for a 3.0% solution. Calvery (3) states that the end point in this titration should be about pH 9.1. It was concluded that the alanine was reasonably pure.

Experiment 11. Sucrose–glucose comparisons.

All glucose solutions were more than 15 hr. old and thus in equilibrium. The following results were obtained:

5.0% sucrose and 8.3% glucose were equally sweet (17 tasters).

10.0% sucrose and 14.4% glucose were equally sweet (14 tasters). The value previously found for 10% sucrose, with 22 to 23 tasters, was 14.7%

glucose. Combining the two series, and weighting the results, gave the value 14.6% glucose.

Experiment 12. Sucrose–galactose comparisons.

The majority of tasters reported no marked taste of galactose solutions other than sweetness. A few recorded secondary taste sensations, variously described as "leaden", "like dilute ink", "woody". One reported that 8% sucrose solution was "bitter or flat" by contrast with 10% galactose; he was of course ignorant of the nature of the solutions tasted.

All galactose solutions were made up at least 15 hr. before use, and none were used when more than 24 hr. old. The following results are thus for an equilibrium mixture of alpha- and beta-galactose:

5.0% galactose and 2.5% sucrose were equally sweet.

10.0% galactose and 6.0% sucrose were equally sweet.

15.0% galactose and 10.0% sucrose were equally sweet.

Experiment 13. Comparison of a galactose–glucose mixture with glucose solutions.

All solutions were made up at least 16 hr. before use. A mixture of 4% galactose plus 4% glucose was used.

By calculation from Fig. 3:

4.0% galactose	=	3.8% glucose
4.0% glucose	=	4.0% glucose
Total		7.8% glucose
Found		7.7% glucose

Experiment 14. Sucrose–mannitol comparisons.

The majority of the tasters noticed no particular after-taste of mannitol. Those noticing any secondary effect variously termed it "flat", or "woody", or "not easily described". One thought it somewhat astringent; none found it bitter.

Results:

5.0% mannitol and 2.45% sucrose were equally sweet.

10.0% mannitol and 5.53% sucrose were equally sweet.

15.0% mannitol and 9.8% sucrose were equally sweet.

Experiment 15. Comparisons between soluble saccharine and sucrose.

Difficulty was experienced, the after-bitterness of the soluble saccharine confusing most tasters, especially with the more concentrated solutions. When the saccharine solutions were repeatedly tasted, alternating with sucrose solutions, the sweetness of the former seemed to diminish. Great variations in results with individual tasters prevents any stress being placed on the calculated values. These were:

2.0% sucrose and 0.0049% soluble saccharine were equally sweet.

5.0% sucrose was not less sweet than 0.024% soluble saccharine.

Attempts to make comparisons with 8.0 and 10.0% sucrose failed completely, because of the dominant bitterness of the saccharine solutions.

Experiment 16. Sucrose–dulcine comparisons.

Dulcine gave difficulty, but less so than soluble saccharine. Its sweet taste seemed to persist (even after rinsing the mouth with water) so that some tasters found that a sucrose solution appeared to be sweeter when tasted after, than when tasted before, a dulcine solution. Conclusions from the results cannot be stressed, especially those for the higher concentrations, since analysis of the records for individual tasters showed a greater proportion of irregularities and contradictions than usual. Results:

0.0125% dulcine is equal in sweetness to 3.35% sucrose.

0.025% dulcine is equal in sweetness to 4.14% sucrose.

0.050% dulcine is equal in sweetness to 4.55% sucrose.

Experiment 17. Comparison of sucrose–dulcine mixtures with sucrose solutions.

Although the precise values found for dulcine cannot be stressed, it was thought that errors affecting its measurement would affect mixtures containing it in similar fashion and neutralize each other.

(i) Mixture of 0.0125% dulcine plus 3.0% sucrose.

Theory: If summation be in terms of sucrose,

0.0125% dulcine	=	3.35% sucrose (from Fig. 3)
3.0% sucrose	=	3.0% sucrose
Total		6.35% sucrose
Found		7.95% sucrose

If summation be in terms of glucose, then from the curves in Fig. 3:

0.0125% dulcine	= 3.35% sucrose	= 6.0% glucose
	3.0% sucrose	= 5.45% glucose
Total	11.45% glucose	= 7.35% sucrose
Found		7.95% sucrose

(ii) Mixture of 0.025% dulcine plus 5.0% sucrose.

Theory: If summation be in terms of sucrose,

0.025% dulcine	=	4.1% sucrose
5.0% sucrose	=	5.0% sucrose
Total		9.1% sucrose
Found		10.85% sucrose

If summation be in terms of glucose, then from the curves in Fig. 3:

0.025% dulcine	= 4.1% sucrose	= 7.1% glucose
5.0% sucrose		= 8.3% glucose
Total	15.4% glucose	= 10.7% sucrose (from Fig. 3)
Found		10.85% sucrose

Experiment 18. Sucrose–glycine comparisons.

Most tasters had no difficulty in distinguishing glycine solutions from those of sucrose. A variety of descriptions was applied to the glycine solutions, as "bitter"; "tart, like alum"; "like horse-radish"; "sour"; "acid"; "having a sharp sweetness". It would appear that there is a definitely superimposed acid taste. Results:

5.0% glycine is equal in sweetness to 3.25% sucrose.
10.0% glycine is equal in sweetness to 5.5% sucrose.

Experiment 19. Comparison of a glycine–sucrose mixture with sucrose solutions.

A mixture containing 5.0% glycine plus 5.0% sucrose was tested.

In terms of sucrose:

5.0% glycine	=	3.25% sucrose
5.0% sucrose	=	5.0% sucrose
Total		8.25% sucrose
Found		6.5% sucrose

In terms of glucose:

5.0% glycine	= 3.25% sucrose	=	5.8% glucose (from Fig. 3)
5.0% sucrose		=	8.3% glucose
Total	14.1% glucose	=	9.55% sucrose (from Fig. 3)
Found			6.5% sucrose

Experiment 20. Comparison of a glycine–glucose mixture with glucose solutions.

All solutions were made up 16 hr. or more before use. A 5.0% glycine plus 5.0% glucose mixture was tested.

In terms of glucose:

5.0% glycine	=	5.8% glucose (see above)
5.0% glucose	=	5.0% glucose
Total		10.8% glucose
Found		9.9% glucose

Experiment 21. Comparison of *dl*-alanine and sucrose.

Time permitted only a single determination—with 3.0% alanine. This solution was described, by contrast with the sucrose, as "sour", "sharp", and "ether-like". Using 13 tasters only, it was found equal in sweetness to 3.0% sucrose.

Experiment 22. Comparison of an alanine–sucrose mixture with sucrose solutions; 3.0% *dl*-alanine plus 3.0% sucrose was used. Again, only 13 tasters were available.

Theory:

3.0% *dl*-alanine = 3.0% sucrose = 5.45% glucose (from Fig. 3).
3.0% sucrose = 3.0% sucrose = 5.45% glucose
Total 6.0% sucrose or 10.9 % glucose (which, from Fig. 3 = 6.8% sucrose)
Found 5.3% sucrose

Experiment 23. Comparison of an alanine–glycine mixture against sucrose solutions.

The mixture contained 3.0% *dl*-alanine plus 5.0% glycine.

Theory:

3.0% *dl*-alanine = 3.0% sucrose = 5.45% glucose
5.0% glycine = 3.25% sucrose = 5.8% glucose
Total 6.25% sucrose or 11.25% glucose (which, from Fig. 3 = 7.2% sucrose)
Found 5.66% sucrose

Discussion of Results

The Method of Measurement and the Nature of Results Deducible from It

The method has already been fully described (5). It is based on the assumption that, if the number of tasters be sufficiently large, there will be an even distribution about the calculated mean value, which is considered to be the value sought. That this assumption is approximately true is shown in Fig. 1, which illustrates some fairly even distributions and others less satisfactory.

The precise significance of the value calculated from any series of observations calls for comment. Taste sensations are reactions to stimuli received by taste buds, mediated through definite nerve channels, and reaching consciousness at certain brain centres. The responses are those of individuals; our knowledge of sensations is based upon summation of experiences of many individuals. These separate experiences may vary. The most extreme variation so far recorded is the response to the stimulus of the compound phenylthiocarbamide, a substance that to 70% of people has the bitterness of quinine, but to the other 30% is tasteless (1). Of the tasters used in the tests recorded in this paper 16 out of the 17 were tested with phenylthiocarbamide, and to six (37.5%) it was tasteless. Considering the relatively small number this was a sufficiently good indication that they represented a normal section of the population as far as phenylthiocarbamide is concerned, although they were a selected group, as far as delicacy of perception of sweetness is concerned.

So far no similar phenomenon has been recorded with regard to sweetness. Yet analysis of the results obtained with different members of the group indicates that each seems to have an individual conception of what is sweetness, and of degrees of sweetness. When sweetnesses of solutions of two different compounds are compared the presence of the other tastes or flavours that

most sweet compounds possess modifies the view of the individual taster, sometimes very perceptibly. This is illustrated by the records of two of the group of tasters who may be termed *A* and *B*. To *A*, sucrose seems to

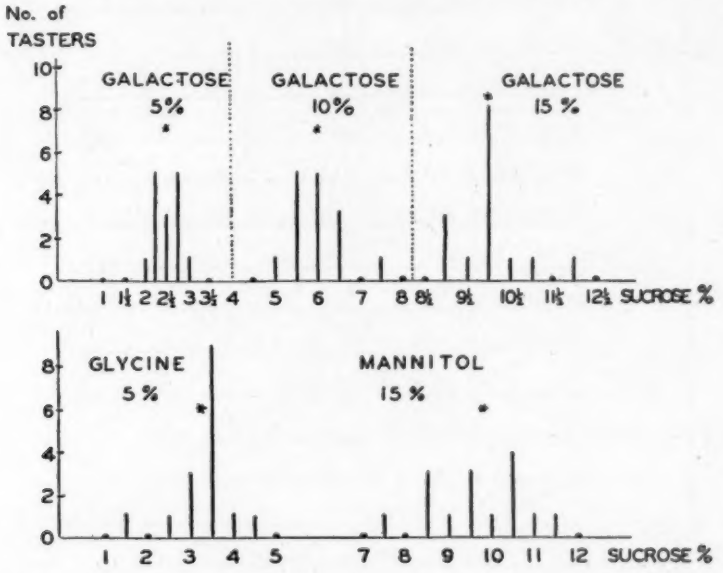

FIG. 1. *Distribution of individual results about the calculated mean (indicated by an asterisk). Values on base lines show the actual percentage solutions of sucrose tested against the percentage concentrations of the other compounds stated. Dots on base lines show absence of any positive results for those values.*

be sweeter than it does to *B*, so that for *A* a lower concentration of sucrose is usually required to give him a sensation of sweetness equal to that of some solution of another compound, than *B* needs. This is well shown in Fig. 2. In comparisons of sucrose solutions with 10% mannitol *A* and *B* were in agreement with themselves and with the majority verdict, but for all other solutions the type of difference just indicated was exhibited, while when solutions containing glycine or alanine were compared with sucrose solutions their results were actually the extremes recorded in almost every case.

This divergence of opinion exhibited by individuals stresses the conclusion that the most that can usefully be sought for is the average opinion of a number of individuals; all results dealing with relative sweetnesses can only be approximations to such averages and need not be true for any particular individual. However, as has already been pointed out (4) the majority of people do not have a delicate perception of the sweetness taste, and such average results are sufficiently applicable to them.

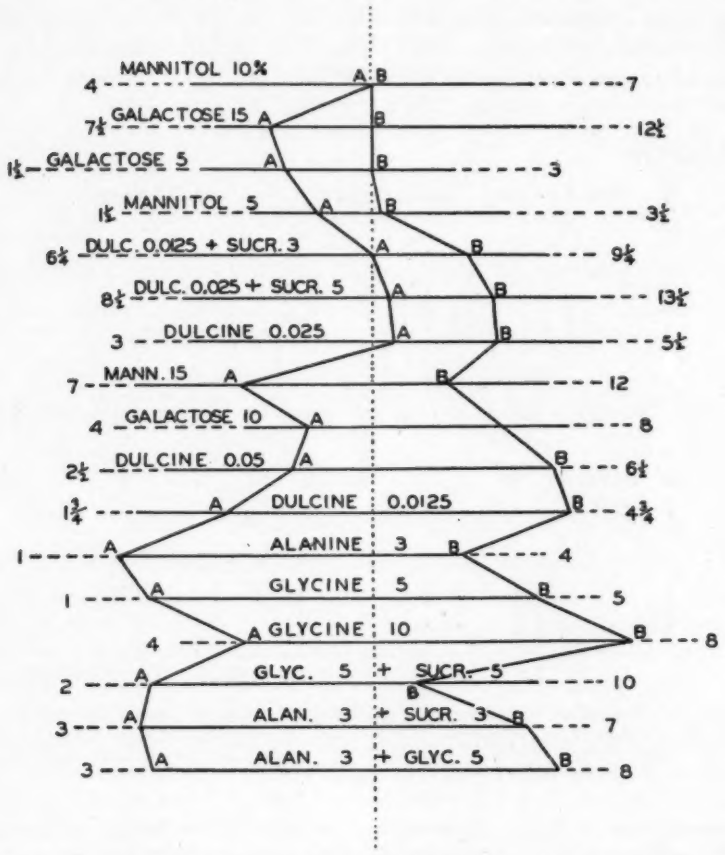

FIG. 2. *Illustration of difference in results given by two individual tasters A and B, in comparisons between solutions of various sweet compounds or mixtures and sucrose. The horizontal lines show the range of sucrose solutions tested in any single experiment, as indicated by the end figures (% sucrose) and have been made of equal length to facilitate comparison. The solid parts of these lines indicate the range of values found by different individuals of the group of tasters. The values found by A and B are indicated and are joined. The dotted vertical line joins the mean values found by the whole group for each comparison. The value shown after each sweet compound indicates the percentage concentration used.*

General Results

Fig. 3 shows all the comparisons with sucrose that have so far been made in this series. It is obvious that glucose, galactose, and mannitol have almost equal sweetness. (In Figs. 3, 4, 5, and 6 the data used for fructose include Dahlberg and Penczek's values (6).)

In Fig. 4 values are expressed in gm-mol. %, instead of actual weight % (as already defined). The order is slightly changed; lactose is slightly sweeter, molecule for molecule, than glucose, and glycerol is much less sweet.

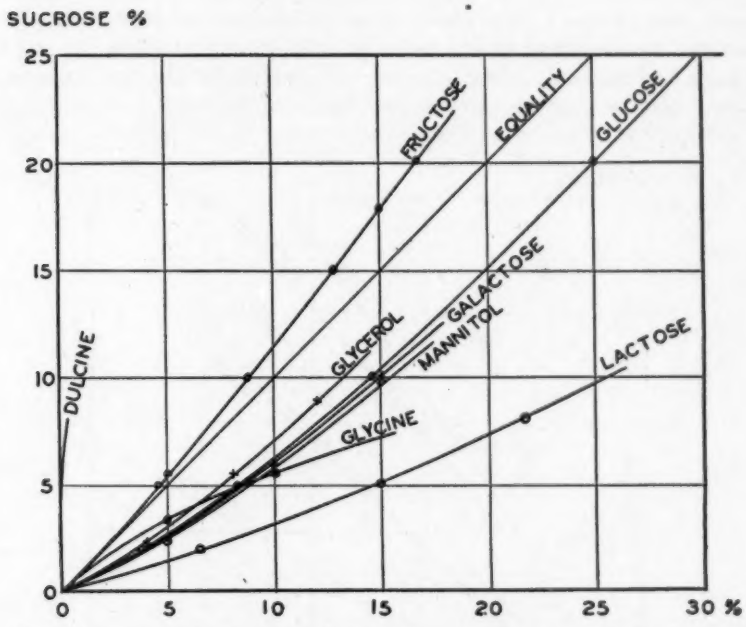

FIG. 3. *Curves showing the sweetness of various compounds, compared with sucrose (from data in this and previous papers of the series; data for fructose include Dahlberg and Penczek's values). The dulcine curve only approximates to the values found.*

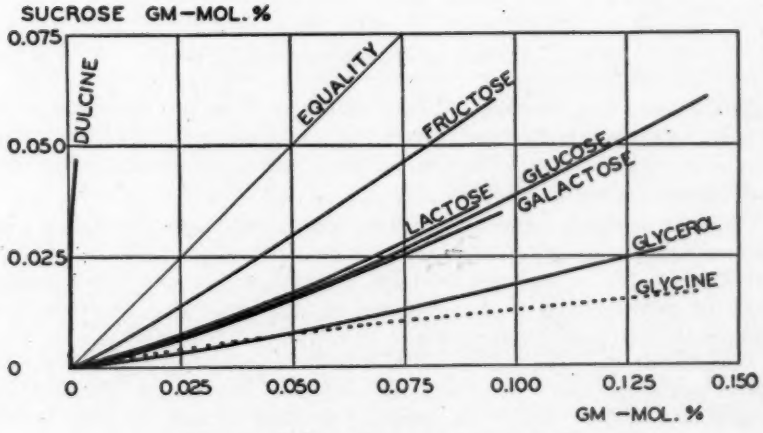

FIG. 4. *As Fig. 3, but values in gm-mol. %.*

In Fig. 5, values for the other compounds are plotted against those for glucose, and within the limits of error of experiment the values for glycerol, galactose, mannitol, and lactose lie on straight lines, while those for dulcine, fructose, sucrose (and glycine) do not. Evidently for the five compounds glucose, galactose, lactose, glycerol, and mannitol the ratios of concentrations of equally sweet solutions are fixed, over the range of concentrations tested.

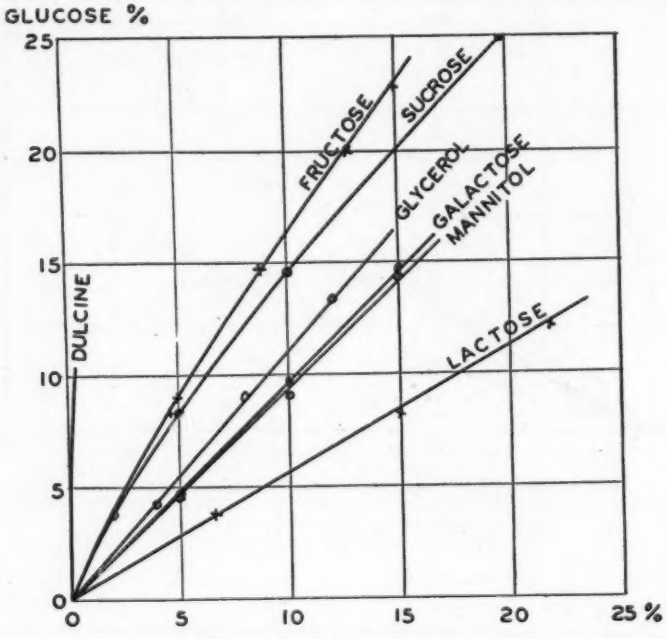

FIG. 5. *As Fig. 3, but all comparisons are with glucose.*

As Dahlberg and Penczek (6) pointed out, and as Fig. 6 indicates, the relation between equally sweet concentrations of sucrose and of other compounds is a log-log one. There is a similar log-log relationship when comparisons are made with fructose.

The sucrose–glucose values previously determined (4, 5) were based upon tests with earlier groups of tasters and differ a little from those of Dahlberg and Penczek (6). It seemed desirable to check my results, using another group of tasters who had already acquired some experience in other tests The results (for equilibrium mixtures of alpha- and beta-glucose) are given in Experiment 11. The glucose value 8.3% corresponding to 5.0% sucrose was in exact agreement with that obtained from the sucrose–glucose curve already drawn (5). That corresponding to 10% sucrose (14.4%) was in good agreement with the earlier figure (14.7%), and gave a weighted figure, for all tasters used, of 14.6%, which, with the other values found for sucrose–

glucose, probably approximates closely to the average values, as defined above, *for the equilibrium mixture.*

The values for soluble saccharine (Experiment 15) indicate a relative sweetness (compared with sucrose) of the order found by others and a marked change with changing concentration. Precise values have still to be determined.

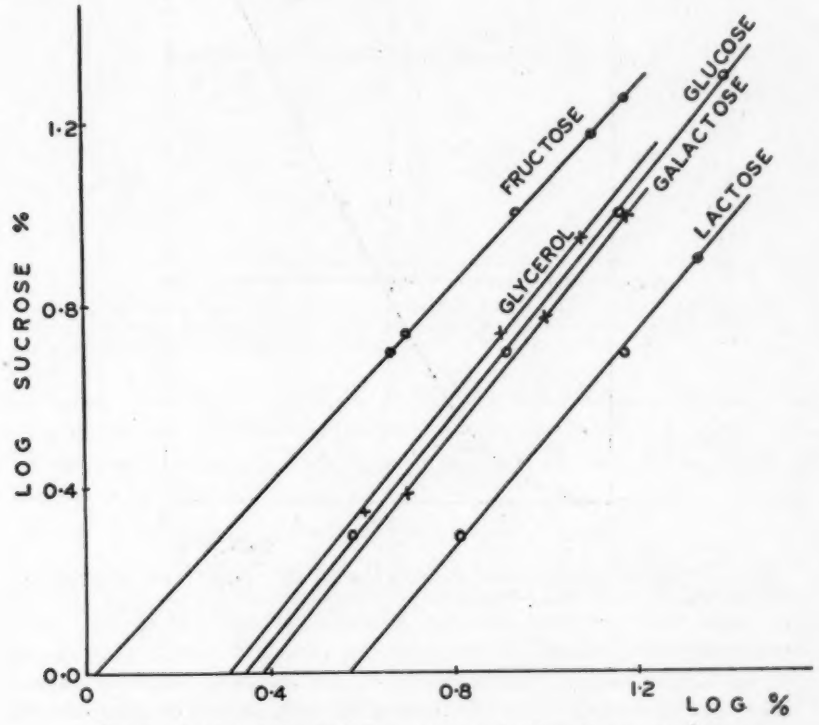

FIG. 6. *Log-log relationship between sucrose and various other sweet compounds.*

The values for dulcine (Experiment 16) are of the same order as those found by Paul (16) though not in very good agreement with them (cf. Fig. 7). The distribution of values is too great (see protocols), and I hope to make some further measurements of dulcine.

My group of tasters found glycine and alanine relatively much less sweet (Experiments 18 and 21) than did those of Heiduschka *et al.* (12, 13), and this is shown in Fig. 8. I believe that my results are definitely more accurate. Both Paul and Heiduschka used a method in which solutions of two compounds were first tasted in one order (XY) and, later, in the reversed order (YX). I tested this method in early work and found it most unsatisfactory (4).

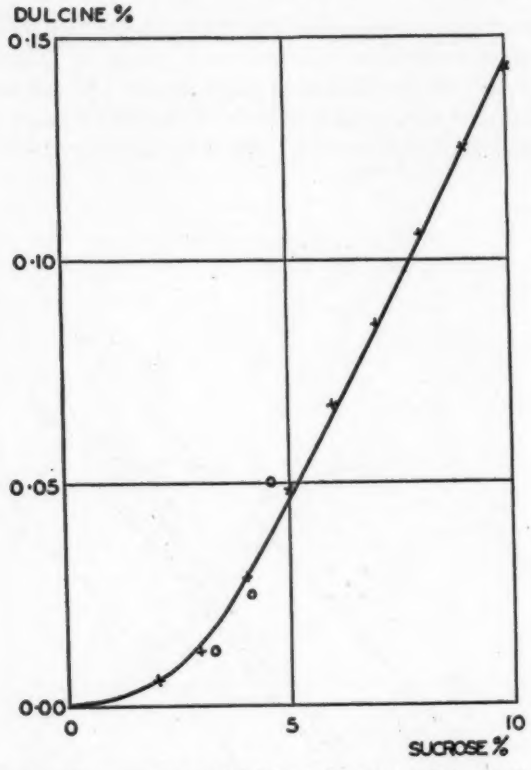

FIG. 7. *Curve relating sweetnesses of dulcine and sucrose. Values indicated by crosses are from Paul; by circles, from present paper.*

Experiments with Mixtures

In the second paper of this series (5) it was shown for sucrose, glucose, lactose, and glycerol that the sweetness of mixtures of two or more of these compounds could be calculated, if the composition of a mixture was known; if the sweetness of each component was evaluated in terms of glucose (or lactose, or glycerol), the sum was the sweetness of the mixture in terms of glucose (or lactose, or glycerol), and this, by reference to the glucose–sucrose curve, could be also expressed in terms of sucrose.

Experiment 13 shows that this also holds true for mixtures containing galactose, and it probably holds true for mannitol.

Since Paul's data (16) suggested that a similar additive relationship existed for sucrose, saccharine, and dulcine, in terms of sucrose, it seemed desirable to ascertain whether they should be equated in terms of sucrose, or of glucose.

Experiment 17 shows definitely that, as far as dulcine is concerned, sucrose cannot be taken as the basis for such calculations. The agreement between

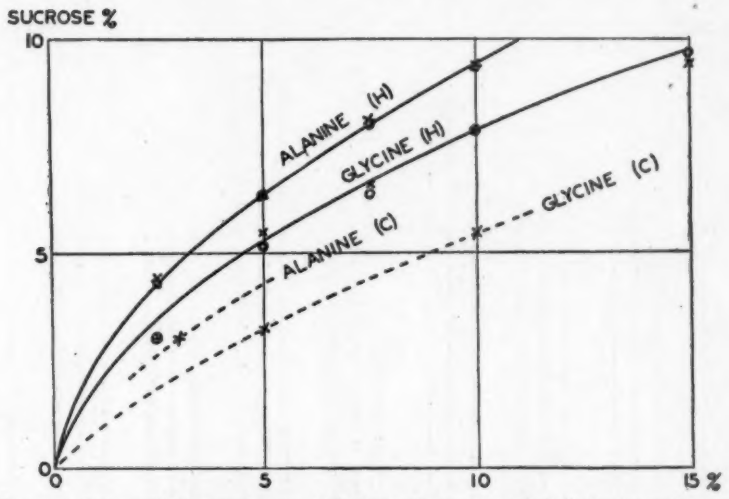

FIG. 8. *Curves relating sweetnesses of glycine and sucrose, and of dl-alanine and sucrose; (H), according to Heiduschka, (C) according to data in present paper. Circles are values calculated by Pauli's method; crosses, values calculated as in this series.*

the values calculated in terms of glucose and those actually found is not quite satisfactory and indicates that further study is needed.

Results with mixtures containing glycine and alanine fall into quite a different category.

Experiments with Mixtures Containing Glycine and Alanine

The result of Heiduschka *et al.* (13) with a mixture of alanine and glycine has been referred to; Experiments 19, 20, 22, and 23 definitely support this result, but indicate more than these investigators inferred. The presence of glycine or of alanine in a sweet mixture definitely lessens the potential sweetness of the mixture (the sum of the sweetnesses of glycine or alanine plus another component such as glucose or sucrose). The effect cannot be due to the second component, since, as has been shown, glucose or sucrose in mixture with other sugars gives a truly additive effect (in terms of glucose).

The apparent anomaly is illustrated in Figs. 9 and 10, in which the results for all mixtures measured in this series are shown diagrammatically. In Fig. 9 each pair of vertical columns is, as measured, of equal sweetness. All values are calculated in terms of sucrose (from the curves in Fig. 3). All heights for the mixtures (left columns) are lower than for the comparison sugar (right column) except when glycine or alanine is present, when the rev erse is usually true.

Hence when mixtures are equated in terms of sucrose, relatively more sucrose is needed for equal sweetness except in presence of glycine or alanine, when usually relatively less sucrose is needed.

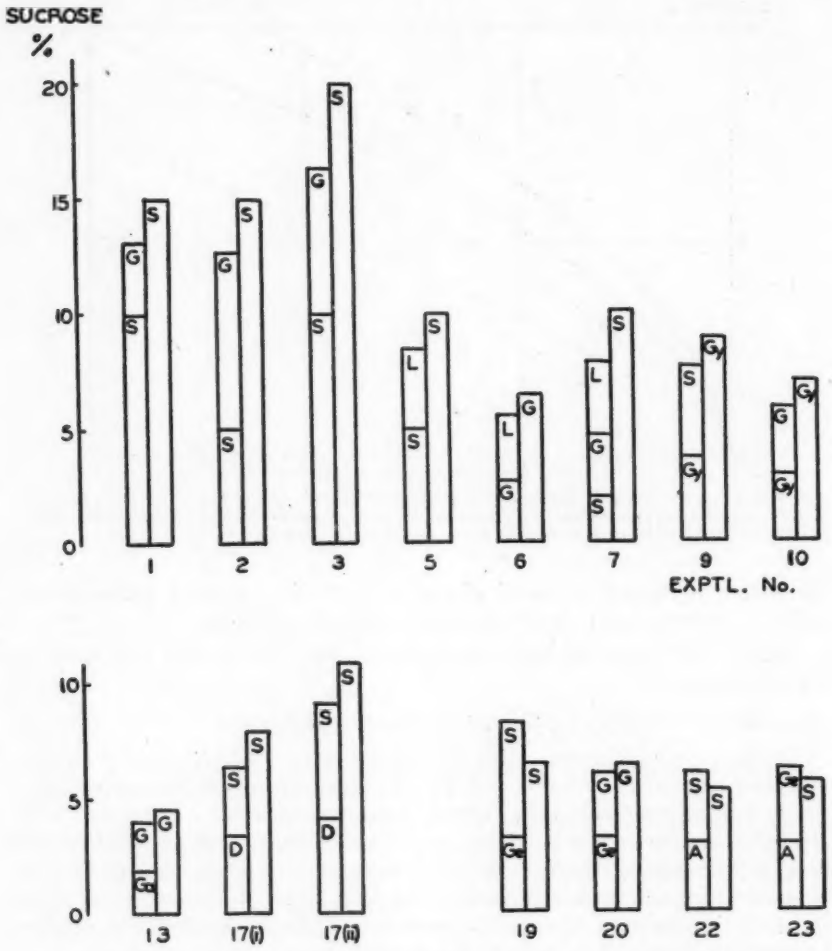

FIG. 9. *Evaluation of the sweetness of mixtures. All data are expressed in terms of sucrose (from curves in Fig. 3). For interpretation see text. A, alanine; D, dulcine; G, glucose; Ga, galactose; Ge, glycine; Gy, glycerol; L, lactose; S, sucrose.*

In Fig. 10 all values are calculated in terms of glucose. For the first 11 mixtures the heights of the pairs are equal within the limits of experimental error, except in Experiment 17 (i) for a dulcine mixture, which needs further examination. For all mixtures containing glycine and alanine there is no such equality, *less* of the comparison-sugar being required.

Thus a mixture containing a sugar and glycine or alanine, or a mixture of these two amino acids, is *less sweet* than the sum of the sweetnesses of its

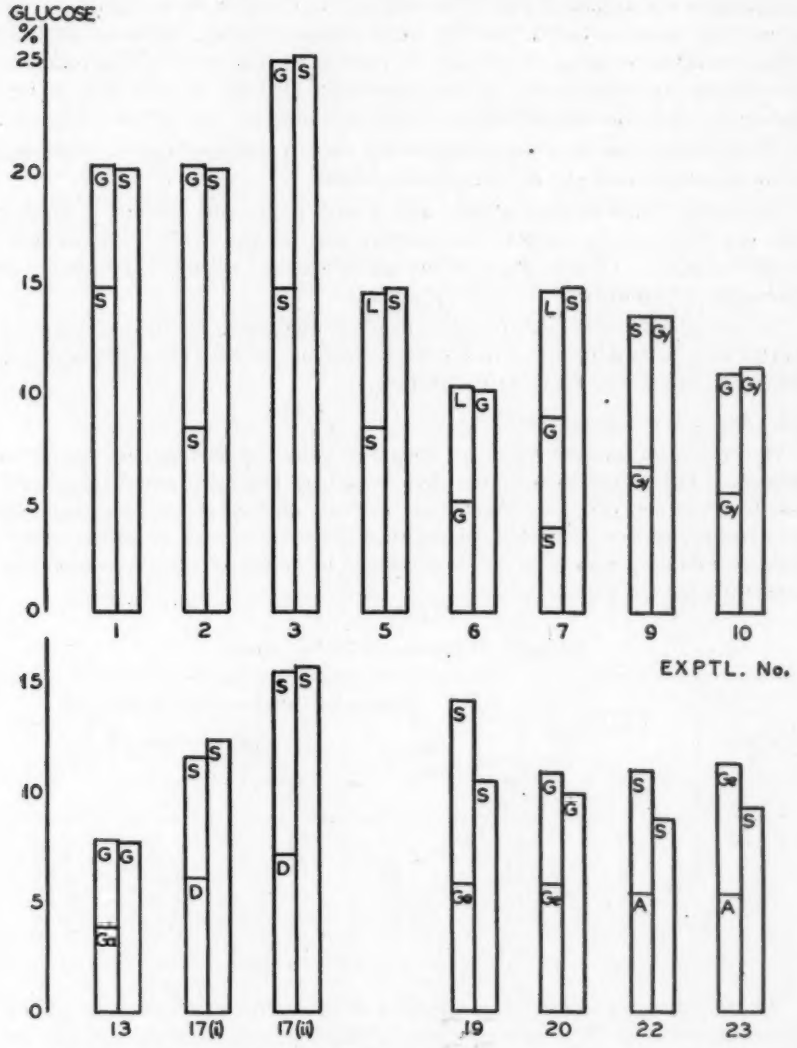

FIG. 10. *Evaluation of sweetness of mixtures. All data are expressed in terms of glucose (from curves in Figs. 3 and 5). For interpretation see text. Letters have same significance as in Fig. 9.*

components, measured in terms of glucose, and is usually less sweet even when measured in terms of sucrose.

Obviously one thinks first of formation of compounds, less sweet, between the amino acids and the sugars. Both glycine and alanine do form additive

compounds with glucose, and with fructose, but only to a negligible extent in neutral solutions (14, 15, 8–11), while sucrose does not unite at all with these amino acids (14). Moreover, in confirmation of this, it was found in the present experiments that in a mixture of glycine and sucrose, after 40 hr., the optical rotation was unchanged within the limit of error of measurement.

Hence, formation of a non-sweet or less sweet compound can be ruled out as an explanation of the decrease in sweetness.

In neutral solutions both glycine and alanine are largely present as dipolar ions (zwitterions) (7), so that one wonders whether the effect is due to zwitterions as such. Further experiments are necessary before it is justifiable to formulate a hypothesis.

However, until this "subtraction effect" is explained, it will be necessary to test any compound in mixture with sucrose or glucose before the additive effect can be claimed for it with certainty.

The Sweetness of Invert Sugar

Hydrolysis of sucrose gives no constant value for change in sweetness. Accepting the values for fructose determined by Dahlberg and Penczek (6) and by Cameron (4) as approximately correct, and assuming that fructose behaves in mixtures like other sugars, then inversion of sucrose affects sweetness as follows, expressing all sweetnesses in terms of the corresponding concentrations of glucose.

TABLE IV

RELATIVE SWEETNESS OF INVERT SUGAR

Sucrose, %	Corresponding invert sugar		Equivalent sweetness in terms of glucose						
			Original sucrose, %	Hydrolysed products					Total, %
	Glucose, %	Fructose, %		Glucose, %		Fructose, %			
1.0	0.53	0.53	2.10	0.53	×	1.15	=		1.68
5.0	2.63	2.63	8.30	2.63	×	5.10	=		7.73
9.0	4.74	4.74	13.45	4.74	×	8.60	=		13.34
10.0	5 26	5.26	14.60	5.26	×	9.38	=		14.64
15.0	7.89	7.89	19.95	7.89	×	13.40	=		21.29
20.0	10.60	10.60	25.00	10.60	×	17.10	=		27.70

Hence hydrolysis of sucrose produces a slight decrease in sweetness in low concentrations, for 10% sucrose there is practically no change, and for increasingly higher concentrations an increasingly greater though always only slight increase results.

Iso-sweet Iso-caloric Mixtures

It has already been pointed out that it is possible to determine the composition of certain mixtures of glucose and sucrose that are equal both in sweetness and in caloric value (5). Fig. 11 demonstrates how this can be done.

To construct an iso-sweet curve for $X\%$ sucrose, let $Y\%$ sucrose be some lesser concentration, and X' and $Y'\%$ be the corresponding concentrations of glucose of equal sweetness (as determined from the glucose–sucrose sweetness curve reproduced in the figure). Then a mixture containing $(X' - Y')\%$ glucose and $Y\%$ sucrose will be equal in sweetness to $X\%$ sucrose, and Y and $(X' - Y')$ give a point on the curve that passes through X.

To construct iso-caloric curves, using the accepted values 3.96 and 3.74 Cal. per gm. sucrose and glucose respectively, $X\%$ sucrose and $(X \times 1.059)\%$ glucose have equal caloric value, and this is true for all points on the straight line connecting them.

The intersection of corresponding iso-sweet and iso-caloric lines gives a single value for which the mixture is both iso-sweet and iso-caloric. Connecting such values, the iso-sweet iso-caloric curve is obtained. As Fig. 11 indicates, the limiting value for such a mixture lies between 12 and 13% sucrose, and for lower values no such iso-sweet iso-caloric mixtures are possible.

The actual values for the circled points on the iso-sweet iso-caloric curve in Fig. 11 are as follows:

(1) 25% sucrose, 990.0 Cal. per litre. Mixture, 6.3% sucrose, 19.8% glucose, 990.0 Cal. per litre.

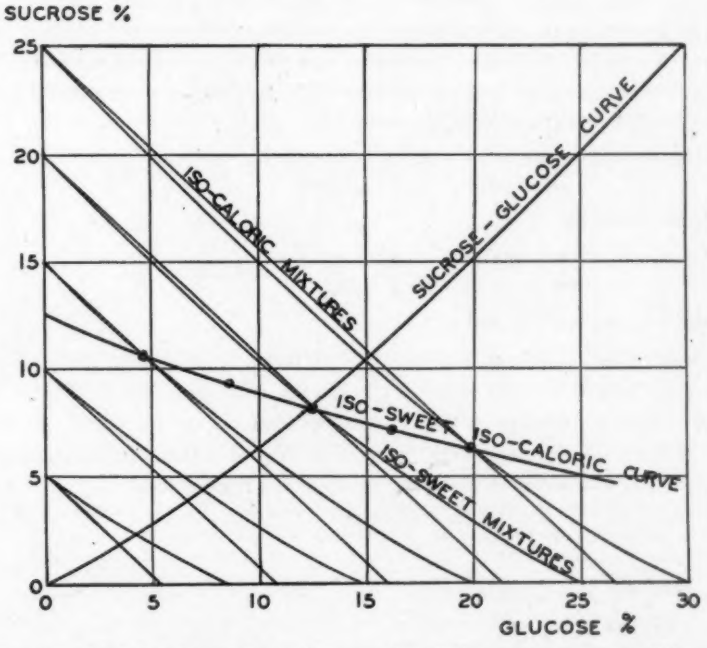

FIG. 11. *Method of determining an iso-sweet, iso-caloric curve for sucrose and glucose.*

(2) 22.5% sucrose, 891.0 Cal. per litre. Mixture, 7.2% sucrose, 16.2% glucose, 891.0 Cal.

(3) 20.0% sucrose, 792.0 Cal. per litre. Mixture, 8.1% sucrose, 12.6% glucose, 792.0 Cal. per litre.

(4) 17.5% sucrose, 693.0 Cal. per litre. Mixture, 9.3% sucrose, 8.68% glucose, 692.9 Cal. per litre.

(5) 15.0% sucrose, 594.0 Cal. per litre. Mixture, 10.6% sucrose, 4.66% glucose, 594.0 Cal. per litre.

The values just given depend of course upon the accuracy of the glucose–sucrose curve employed, but the principle holds, whatever the true values.

The Type Curve for the Relationship Between Sweetness and Concentration

When sweetnesses are compared on a molecular basis, as in Fig. 4, the ratios are approximately (with glucose as standard (100)), lactose, 93; galactose, 104; mannitol, 106; glycerol, 176. The corresponding (changing) values for sucrose are 28 (for 2%), 32 (for 5%), 36 (for 10%), and 42 (for 20%).

Experiment 13 showed that the sweetness of mixtures of glucose and galactose is additive in terms of glucose. When lactose is hydrolysed, 93 molecules yield 93 molecules of glucose plus 93 molecules of galactose, the latter being equal in sweetness to 89 molecules of glucose. Hence lactose equal in sweetness to 100 molecules of glucose hydrolyses to a product equal in sweetness to 182 molecules of glucose, and this ratio holds for any multiple of these molecules and is constant over the range of concentrations tested and within the limit of error of the method.

$$\text{Hence:} \quad \frac{\text{Sweetness of } 1.82 \times C\% \text{ glucose}}{\text{Sweetness of } C\% \text{ glucose}} = \text{Constant},$$

and more generally

$$\frac{\text{Sweetness of } aC\% \text{ glucose}}{\text{Sweetness of } C\% \text{ glucose}} = \text{Constant},$$

whatever the values of a and of C.

Consider a series of concentrations of glucose, a, $2a$, $4a$, $8a$, $16a$, etc., for which the respective sweetnesses are s, s_i, s_{ii}, s_{iii}, s_{iiii}, etc. Then $s_i/s = s_{ii}/s_i = s_{iii}/s_{ii} = s_{iiii}/s_{iii} = \text{etc.} = k$, a constant.

It has been shown, on general principles, that doubling the concentration cannot double the sweetness, which must be less than double (4).

Let $s_i = 2s - b$, where b is small.

Then $s_{ii} = (2s - b)^2/s$

$s_{iii} = (2s - b)^3/s^2$

. . . . . .

$s_n = (2s - b)^n/s^{n-1}$

This relationship can be used to draw a curve relating sweetness to concentration. If, e.g., s is 2, a is 2, and b is 0.1, then

$$\begin{aligned} 2a &= 4;\ s_i = 4 - 0.1 = 3.9 \\ 4a &= 8;\ s_{ii} = 7.6 \\ 8a &= 16;\ s_{iii} = 14.83 \\ 16a &= 32;\ s_{iiii} = 28.92 \\ 32a &= 64;\ s_{iiiii} = 56.39, \text{ etc.} \end{aligned}$$

These values have been used to construct the curve, A, in Fig. 12. For glucose the value of b is probably not 0.1 but some similar value, and the curve for glucose will be similar in type. Assuming, however, that the curve, A, does represent glucose (taking $a = 0.5\%$ for convenience), then from the curves in Figs. 3 and 5 the corresponding sucrose and lactose curves can be

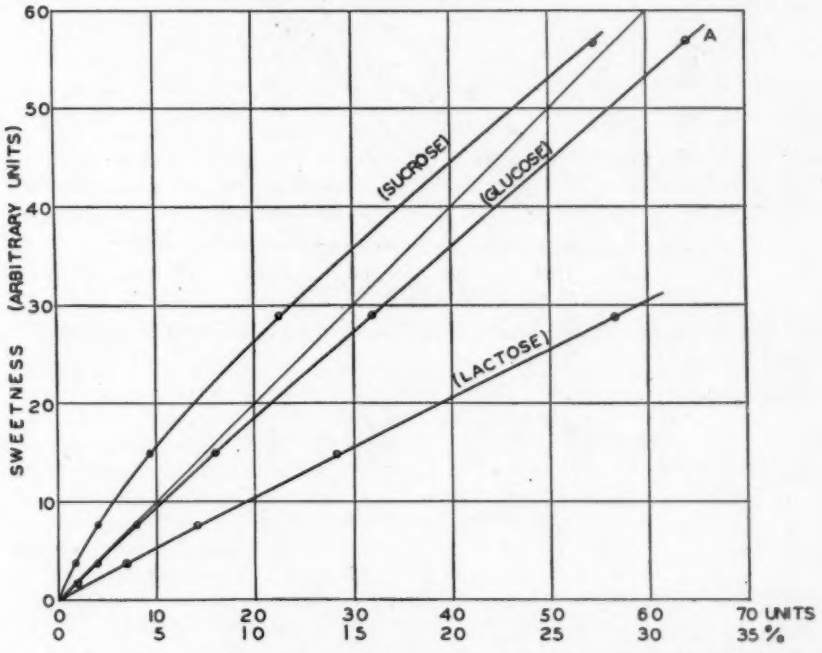

FIG. 12. *Curves relating sweetness and concentration. A, type curve for sugars such as glucose. The curves for sucrose and lactose are drawn on the assumption that A is the actual curve for glucose.*

constructed, as in Fig. 12. These are all log-log curves, as is shown in Fig. 13. It will be seen that glucose and lactose give parallel lines, to which that for sucrose is not parallel.

Mr. Lloyd Dulmage, of the Department of Mathematics of the University of Manitoba, has been good enough to provide me with a more elegant expression of the general relationship for such compounds as glucose.

If S denotes sweetness, and C concentration, and the constant k has the significance already indicated, and if $S = S_a$ for $C = a$, then

$$S = k^n S_a \quad \text{for} \quad C = 2^n a,$$

whence

$$\log S = n \log k + \log S_a \quad \text{and} \quad \log C = n \log 2 + \log a.$$

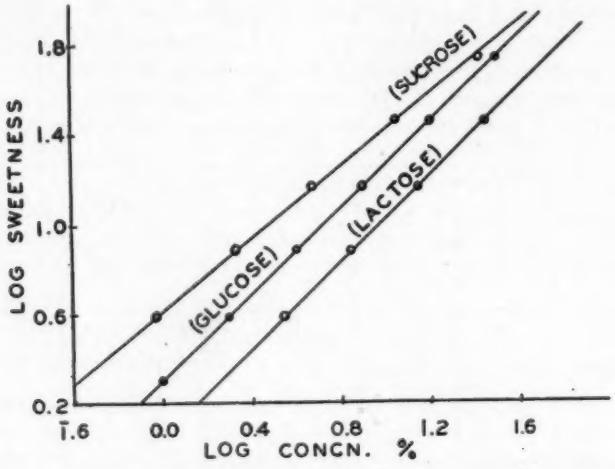

FIG. 13. *Log-log nature of curves relating sweetness and concentration of certain sugars.*

Eliminating n:

$$\frac{\log S - \log S_a}{\log C - \log a} = \frac{\log k}{\log 2} = m(\text{say}).$$

Then

$$\log \frac{S}{S_a} = m \log \frac{C}{a}$$

or

$$\frac{S}{S_a} = \left(\frac{C}{a}\right)^m$$

and

$$\frac{S}{C^m} = \frac{S_a}{a^m}$$

Since k, and hence m, are independent of a, it follows that $\frac{S}{C^m}$ is equal to some constant K, whence

$$S = KC^m, \text{ or, equivalently,}$$
$$\log S = \log K + m \log C,$$

which obviously gives a linear relationship.

Acknowledgments

Thanks are due Dr. F. D. White for making the various tests for purity on the material employed, and Mr. Lloyd Dulmage for the mathematical expression relating sweetness and concentration of glucose.

Thanks are due to the following group of students who acted as tasters in the experiments recorded in this paper: Messrs. J. K. A. Clokie, M. Cohen, J. D. Duncan, W. W. Fox, D. E. Govan, E. D. Herberts, G. Hoe, J. A. Hopkins, J. M. Kidd, A. Miles, H. A. V. Muth, R. H. Parker, G. W. Ritchie, R. T. Ross, T. K. Stevenson, R. B. Sylvestre, T. M. Wallace.

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Protocols of Experiments

The method of calculation has already been described (5). The following abbreviations are used: concns. cpd., for concentrations compared; sucrose sweeter, for number reporting sucrose sweeter, etc.; equality, for number reporting sweetness equal; *M*, for mixture; *A*, for alanine %; *D*, for dulcine %; *G*, for glucose %; *Ga*, for galactose %; *Ge*, for glycine %; *Ma*, for mannitol %; *S*, for sucrose %; *Sa*, for soluble saccharine %. As already stated, the experimental numbers are continued from those in the second paper (5).

Expt. 11 (A). Glucose and 5% sucrose.

Triads: 5*S*/7.25*G*/8.75*G*; 5*S*/7.75*G*/9.25*G*; 5*S*/8.25*G*/9.75*G*.

Concns. cpd.:	5*S*/7.25*G*	5*S*/7.75*G*	5*S*/8.25*G*	5*S*/8.75*G*
Sucrose sweeter:	14 (100%)	11 (12½) (89%)	4 (5½) (39%)	4 (5) (36%)
Glucose sweeter:	0 (0%)	0 (1½) (11%)	7 (8½) (61%)	8 (9) (64%)
Equality:	0	3	3	2

Concns. cpd.:	5*S*/9.25*G*	5*S*/9.75*G*
Sucrose sweeter:	0 (0%)	0 (0%)
Glucose sweeter:	14 (100%)	14 (100%)
Equality:	0	0

Expt. 11 (B). Glucose and 10% sucrose.

Triads: 10*S*/11½*G*/13½*G*; 10*S*/12½*G*/14½*G*; 10*S*/13½*G*/15½*G*; 10*S*/14½*G*/16½*G*; 10*S*/12*G*/15*G*; 10*S*/13*G*/16*G*; 10*S*/14*G*/17*G*.

Concns. cpd.:	10*S*/11½*G*	10*S*/12*G*	10*S*/12½*G*	10*S*/13*G*
Sucrose sweeter:	14 (100%)	13 (13½) (96½%)	14 (100%)	14 (100%)
Glucose sweeter:	0 (0%)	0 (½) (3½%)	0 (0%)	0 (0%)
Equality:	0	1	0	0

Concns. cpd.:	10*S*/13½*G*	10*S*/14*G*	10*S*/14½*G*	10*S*/15*G*
Sucrose sweeter:	14 (100%)	6 (6½) (46½%)	8 (8½) (61%)	3 (3½) (25%)
Glucose sweeter:	0 (0%)	7 (7½) (53½%)	5 (5½) (39%)	10 (10½) (75%)
Equality:	0	1	1	1

Concns. cpd.:	10*S*/15½*G*	10*S*/16*G*	10*S*/16½*G*	10*S*/17*G*
Sucrose sweeter:	1 (2) (14%)	0 (½) (3½%)	0 (0%)	0 (0%)
Glucose sweeter:	11 (12) (86%)	13 (13½) (96½%)	14 (100%)	14 (100%)
Equality:	2	1	0	0

Summation of all values for glucose and 10% sucrose (Expts. I*B* and *11B*):

Concns. cpd.:	10*S*/11½*G*	10*S*/12*G*	10*S*/12½*G*	10*S*/13*G*
Sucrose sweeter:	37 (100%)	36 (36½) (98½%)	37 (100%)	37 (100%)
Glucose sweeter:	0 (0%)	0 (½) (1½%)	0 (0%)	0 (0%)
Equality:	0	1	0	0

Concns. cpd.:	10*S*/13½*G*	10*S*/14*G*	10*S*/14½*G*	10*S*/15*G*
Sucrose sweeter:	31 (33) (89%)	23 (24) (65%)	17 (20) (55½%)	12 (14) (38%)
Glucose sweeter:	2 (4) (11%)	12 (13) (35%)	13 (16) (44½%)	21 (23) (62%)
Equality:	4	2	6	4

Concns. cpd.:	10*S*/15½*G*	10*S*/16*G*	10*S*/16½*G*	10*S*/17*G*
Sucrose sweeter:	4 (5½) (15%)	1 (2) (5½%)	0 (0%)	0 (0%)
Glucose sweeter:	30 (31½) (85%)	33 (34) (94½%)	36 (100%)	37 (100%)
Equality:	3	2	0	0

Expt. 12 (A). Sucrose and 5% galactose.

Triads: 5*Ga*/1*S*/3*S*; 5*Ga*/2*S*/4*S*. Also 5*Ga*/1½*S*/2½*S*/3½*S*.

Concns. cpd.:	5*Ga*/1*S*	5*Ga*/1½*S*	5*Ga*/2*S*	5*Ga*/2½*S*
Galactose sweeter:	15 (100%)	15 (100%)	13 (14) (93%)	6 (7½) (50%)
Sucrose sweeter:	0 (0%)	0 (0%)	0 (1) (7%)	6 (7½) (50%)
Equality:	0	0	2	3

Concns. cpd.:	5*Ga*/3*S*	5*Ga*/3½*S*	5*Ga*/4*S*
Galactose sweeter:	0 (½) (3%)	0 (0%)	0 (0%)
Sucrose sweeter:	14 (14½) (97%)	15 (100%)	15 (100%)
Equality:	1	0	0

Expt. 12 (B). Sucrose and 10% galactose.

Triads: 10*Ga*/4*S*/8*S*; 10*Ga*/6*S*/10*S*; 10*Ga*/5*S*/7*S*.

Concns. cpd.:	10*Ga*/4*S*	10*Ga*/5*S*	10*Ga*/6*S*	10*Ga*/7*S*
Galactose sweeter:	15 (100%)	13 (14) (93%)	4 (6½) (43%)	2 (13%)
Sucrose sweeter:	0 (0%)	0 (1) (7%)	6 (8½) (57%)	13 (87%)
Equality:	0	2	5	0

Concns. cpd.:	10*Ga*/8*S*
Galactose sweeter:	0 (0%)
Sucrose sweeter:	15 (100%)
Equality:	0

Expt. 12 (C). Sucrose and 15% galactose.

Triads: 15*Ga*/7½*S*/10½*S*; 15*Ga*/8½*S*/11½*S*; 15*Ga*/9½*S*/12½*S*.

Concns. cpd.:	15*Ga*/7½*S*	15*Ga*/8½*S*	15*Ga*/9½*S*	15*Ga*/10½*S*
Galactose sweeter:	15 (100%)	14 (14½) (97%)	8 (9½) (63%)	4 (4½) (30%)
Sucrose sweeter:	0 (0%)	0 (½) (3%)	4 (5½) (37%)	10 (10½) (70%)
Equality:	0	1	3	1

Concns. cpd.:	15*Ga*/11½*G*	15*Ga*/12½*S*
Galactose sweeter:	1 (1½) (10%)	0 (0%)
Sucrose sweeter:	13 (13½) (90%)	15 (100%)
Equality:	1	0

Expt. 13. Glucose and a mixture of 4% glucose and 4% galactose.

Triads: *M*/5*G*/9*G*; *M*/7*G*/11*G*.

Concns. cpd.:	*M*/5*G*	*M*/7*G*	*M*/9*G*	*M*/11*G*
Mixture sweeter:	14 (100%)	10 (11) (79%)	0 (½) (4%)	0 (0%)
Glucose sweeter:	0 (0%)	2 (3) (21%)	13 (13½) (96%)	14 (100%)
Equality:	0	2	1	0

Expt. 14 (A). Sucrose and 5% mannitol.

Triads: 5*Ma*/1*S*/3*S*; 5 *Ma*/2*S*/4*S*; 5*Ma*/2½*S*/3½*S*.

Concns. cpd.:	5*Ma*/1*S*	5*Ma*/1½*S**	5*Ma*/2*S*	5*Ma*/2½*S*
Mannitol sweeter:	16 (100%)	16 (100%)	14 (15) (94%)	2 (6) (37½%)
Sucrose sweeter:	0 (0%)	0 (0%)	0 (1) (6%)	6 (10) (62½%)
Equality:	0	0	2	8

Concns. cpd.:	5*Ma*/3*S*	5*Ma*/3½*S*	5*Ma*/4*S*
Mannitol sweeter:	1 (6%)	0 (0%)	0 (0%)
Sucrose sweeter:	15 (94%)	16 (100%)	16 (100%)
Equality:	0	0	0

Expt. 14 (B). Sucrose and 10% mannitol.

Triads: 10*Ma*/4*S*/8*S*; 10*Ma*/6*S*/10*S*; 10*Ma*/5*S*/7*S*.

Concns. cpd.:	10*Ma*/4*S*	10*Ma*/5*S*	10*Ma*/6*S*	10*Ma*/7*S*
Mannitol sweeter:	14 (100%)	8 (9½) (68%)	4 (5) (36%)	0 (0%)
Sucrose sweeter:	0 (0%)	3 (4½) (32%)	8 (9) (64%)	14 (100%)
Equality:	0	3	2	0

Concns. cpd.:	10*Ma*/8*S*
Mannitol sweeter:	0 (0%)
Sucrose sweeter:	14 (100%)
Equality:	0

* Results assumed, from comparison with those for 5*Ma*/2*S*.

Expt. 14 (C). Sucrose and 15% mannitol.

Triads: (15*Ma*/7*S*/9*S*); 15*Ma*/8*S*/10*S*; 15*Ma*/9*S*/11*S*; (15Ma/12*S*/13*S*).

Concns. cpd.:	15*Ma*/7*S*	15*Ma*/8*S*	15*Ma*/9*S*	15*Ma*/11*S*
Mannitol sweeter:	15 (100%)	13 (13½) (90%)	12 (80%)	7 (7½) (50%)
Sucrose sweeter:	0 (0%)	1 (1½) (10%)	3 (20%)	7 (7½) (50%)
Equality:	0	1	0	1

Concns. cpd.:	15*Ma*/11*S*	15*Ma*/12*S*
Mannitol sweeter:	1 (2) (18%)	0 (0%)
Sucrose sweeter:	12 (13) (82%)	15 (100%)
Equality:	2	0

Expt. 15 (A). Soluble saccharine and 2% sucrose.

Concns. cpd.:	2*S*/0.002*Sa*	2*S*/0.003*Sa*	2*S*/0.004*Sa*	2*S*/0.005*Sa*
Sucrose sweeter:	17 (100%)	16 (94%)	14 (14½) (85%)	5 (5½) (32%)
Sacch. sweeter:	0 (0%)	1 (6%)	2 (2½) (15%)	11 (11½) (68%)
Equality:	0	0	1	1

Concns. cpd.:	2*S*/0.006*Sa*	2*S*/0.007*Sa*	2*S*/0.008*Sa*
Sucrose sweeter:	3 (18%)	2 (12%)	0 (0%)
Sacch. sweeter:	14 (82%)	15 (88%)	17 (100%)
Equality:	0	0	0

Expt. 15 (B). Soluble saccharine and 5% sucrose.

The values show a wide scattering, and the complete range was not determined.

Expt. 16 (A). Sucrose and 0.0125% dulcine.

Triads: *D*/1.75*S*/3.25*S*; *D*/2.25*S*/3.75*S*; *D*/2.75*S*/4.25*S*; (also *D*/4.75*S*).

Concns. cpd.:	*D*/1.75*S*	*D*/2.25*S*	*D*/2.75*S*	*D*/3.25*S*
Dulcine sweeter:	17 (100%)	14 (14½) (85%)	13 (76½%)	12 (13) (76½%)
Sucrose sweeter:	0 (0%)	2 (2½) (15%)	4 (23½%)	3 (4) (23½%)
Equality:	0	1	0	2

Concns. cpd.:	*D*/3.75*S*	*D*/4.25*S*	*D*/4.75*S*
Dulcine sweeter:	3 (18%)	3 (18%)	0 (0%)
Sucrose sweeter:	14 (82%)	14 (82%)	17 (100%)
Equality:	0	0	0

Expt. 16 (B). Sucrose and 0.025% dulcine.

Triads: etc.: *D*/1½*S*/3*S*; *D*/2*S*/3½*S*; *D*/2½*S*/4*S*; also *D*/4½*S*; *D*/5*S*; *D*/5½*S*.

Concns. cpd.:	*D*/1½*S*	*D*/2*S*	*D*/2½*S*	*D*/3*S*
Dulcine sweeter:	17 (100%)	17 (100%)	17 (100%)	17 (100%)
Sucrose sweeter:	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Equality:	0	0	0	0

Concns. cpd.:	*D*/3½*S*	*D*/4*S*	*D*/4½*S*	*D*/5*S*	*D*/5½*S*
Dulcine sweeter:	11 (11½) (68%)	9 (53%)	8 (47%)	1 (6%)	0 (0%)
Sucrose sweeter:	5 (5½) (32%)	8 (47%)	9 (53%)	16 (94%)	17 (100%)
Equality:	1	0	0	0	0

Expt. 16 (C). Sucrose and 0.05% dulcine.

Triads: etc.: *D*/3½*S*/5½*S*; *D*/2½*S*/4½*S*/6½*S*.

Concns. cpd.:	*D*/2.5*S*	*D*/3.5*S*	*D*/4.5*S*	*D*/5.5*S*	*D*/6.5*S*
Dulcine sweeter:	14 (100%)	9 (64%)	10 (71%)	3 (21%)	0 (0%)
Sucrose sweeter:	0 (0%)	5 (36%)	4 (29%)	11 (79%)	14 (100%)
Equality:	0	0	0	0	0

Expt. 17 (i). Sucrose and a mixture of 0.0125% dulcine and 3% sucrose.

Triads: *M*/6.25*S*/7.75*S*; *M*/6.75*S*/8.25*S*; *M*/7.25*S*/8.75*S*; also *M*/9.25*S*.

Concns. cpd.:	*M*/6.25*S*	*M*/6.75*S*	*M*/7.25*S*	*M*/7.75*S*
Mixture sweeter:	16 (100%)	14 (15) (94%)	12 (75%)	12 (12½) (78%)
Sucrose sweeter:	0 (0%)	0 (1) (6%)	4 (25%)	3 (3½) (22%)
Equality:	0	2	0	1

Concns. cpd.:	*M*/8.25*S*	*M*/8.75*S*	*M*/9.25*S*
Mixture sweeter:	6 (37½%)	2 (12½%)	0 (0%)
Sucrose sweeter:	10 (62½%)	14 (87½%)	16 (100%)
Equality:	0	0	0

Expt. 17 (ii). Sucrose and a mixture of 0.025% dulcine and 5% sucrose.

Triads: *M*/7½*S*/10½*S*; *M*/8½*S*/11½*S*; *M*/9½*S*/12½*S*; (*M*/13½*S*/14½*S*).

Concns. cpd.:	*M*/7½*S*	*M*/8½*S*	*M*/9½*S*	*M*/10½*S*
Mixture sweeter:	17 (100%)	17 (100%)	12 (13) (76½%)	7 (9) (53%)
Sucrose sweeter:	0 (0%)	0 (0%)	3 (4) (23½%)	6 (8) (47%)
Equality:	0	0	2	4

Concns. cpd.:	*M*/11½*S*	*M*/12½*S*	*M*/13½*S*
Mixture sweeter:	6 (35%)	3 (18%)	0 (0%)
Sucrose sweeter:	11 (65%)	14 (82%)	17 (100%)
Equality:	0	0	0

Expt. 18 (A). Sucrose and 5% glycine.

Triads: *Ge*/1*S*/5*S*; *Ge*/3*S*/7*S*; *Ge*/2*S*/4*S*.

Concns. cpd.:	*Ge*/1*S*	*Ge*/2*S*	*Ge*/3*S*	*Ge*/4*S*	*Ge*/5*S*
Glycine sweeter:	16 (100%)	15 (94%)	11 (12½) (78%)	1 (1½) (9%)	0 (0%)
Sucrose sweeter:	0 (0%)	1 (6%)	2 (3½) (22%)	14 (14½) (91%)	16 (100%)
Equality:	0	0	3	1	0

Expt. 18 (B). Sucrose and 10% glycine.

Triads: (*Ge*/1*S*/3*S*); *Ge*/3*S*/7*S*; *Ge*/5*S*/9*S*; (*Ge*/7*S*/11*S*); *Ge*/4*S*/6*S*.

Concns. cpd.:	*Ge*/3*S*	*Ge*/4*S*	*Ge*/5*S*	*Ge*/6*S*
Glycine sweeter:	16 (100%)	16 (100%)	8 (9½) (59%)	4 (4½) (28%)
Sucrose sweeter:	0 (0%)	0 (0%)	5 (6½) (41%)	11 (11½) (72%)
Equality:	0	0	3	1

Concns. cpd.:	*Ge*/7*S*	*Ge*/8*S*
Glycine sweeter:	1 (6%)	0 (0%)
Sucrose sweeter:	15 (94%)	16 (100%)
Equality:	0	0

Expt. 19. Sucrose and a mixture of 5% glycine and 5% sucrose.

Triads: *M*/4*S*/8*S*; *M*/6*S*/10*S*; also *M*/2*S*.

Concns. cpd.:	*M*/2*S*	*M*/4*S*	*M*/6*S*	*M*/8*S*	*M*/10*S*
Mixture sweeter:	16 (100%)	15 (94%)	13 (13½) (84%)	1 (6%)	0 (0%)
Sucrose sweeter:	0 (0%)	1 (6%)	2 (2½) (16%)	15 (94%)	16 (100%)
Equality:	0	0	1	0	0

Expt. 20. Glucose and a mixture of 5% glycine and 5% glucose.

Triads: *M*/6*G*/10*G*; M/4*G*/8*G* or *M*/8*G*/12*G*; also M/12*G* or *M*/14*G*.

Concns. cpd.:	*M*/4*S*	*M*/6*S*	*M*/8*S*	M/10*S*
Mixture sweeter:	14 (100%)	14 (100%)	13 (13½) (96%)	4 (6) (43%)
Glucose sweeter:	0 (0%)	0 (0%)	0 (½) (4%)	6 (8) (57%)
Equality:	0	0	1	4

Concns. cpd.:	M/12*S*	*M*/14*S*
Mixture sweeter:	1 (7%)	0 (0%)
Glucose sweeter:	13 (93%)	14 (100%)
Equality:	0	0

Expt. 21. Sucrose and 3% *dl*-alanine.

Triads: *A*/2*S*/4*S*; *A*/3*S*/5*S*; (also *A*/1*S*).

Concns. cpd.:	*A*/1*S*	*A*/2*S*	*A*/3*S*	*A*/4*S*	*A*/5*S*
Alanine sweeter:	13 (100%)	12 (92%)	4 (6½) (50%)	1 (8%)	0 (0%)
Sucrose sweeter:	0 (0%)	1 (8%)	4 (6½) (50%)	12 (92%)	13 (100%)
Equality:	0	0	5	0	0

Expt. 22. Sucrose, and a mixture of 3% *dl*-alanine and 3% sucrose.

Triads: *M*/4*S*/6*S*; *M*/5*S*/7*S*; (also *M*/3*S*).

Concns. cpd.:	*M*/3*S*	*M*/4*S*	*M*/5*S*	*M*/6*S*
Mixture sweeter:	13 (100%)	12 (92%)	9 (10½) (81%)	1 (1½) (12%)
Sucrose sweeter:	0 (0%)	1 (8%)	1 (2½) (19%)	11 (11½) (88%)
Equality:	0	0	3	1

Concns. cpd.:	*M*/7*S*
Mixture sweeter:	0 (0%)
Sucrose sweeter:	13 (100%)
Equality:	0

Expt. 23. Sucrose, and a mixture of 3% *dl*-alanine and 5% glycine.

Triads: *M*/4*S*/6*S*; *M*/3*S*/5*S* or *M*/5*S*/7*S*; (also *M*/8*S*).

Concns. cpd.:	*M*/3*S*	*M*/4*S*	*M*/5*S*	*M*/6*S*
Mixture sweeter:	16 (100%)	15 (94%)	10 (11½) (72%)	6 (7) (44%)
Sucrose sweeter:	0 (0%)	1 (6%)	3 (4½) (28%)	8 (9) (56%)
Equality:	0	0	3	2

Concns. cpd.:	*M*/7*S*	M/8*S*
Mixture sweeter:	1 (1½) (9%)	0 (0%)
Sucrose sweeter:	14 (14½) (91%)	16 (100%)
Equality:	1	0

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